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Zhang Jianglong

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

University of North Dakota
Department of Atmospheric Sciences
4149 University Ave. Stop 9006
Grand Forks, ND 58202-9006

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14. ABSTRACT

Recently, a new aerosol assimilation model (NAVDAS-AOD) was developed to improve the Navy Aerosol Analysis and Prediction System (NAAPS)'s electro-optical propagation forecast capability. In this project, we developed Quality Control and Quality Assurance strategies for the over-ocean Collection 5 Moderate Resolution Imaging Spectroradiometer (MODIS) aerosol product that will be applied to the operational data assimilation scheme. An observational based Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) climatology was also developed and implemented to NAVDAS-AOD for improving vertical representations of aerosol distributions. We also tested the feasibility of aerosol data fusion with the combined use of the MODIS, MODIS DeepBlue, and the Multiangle Imaging SpectroRadiometer (MISR) aerosol products. Using the NAAPS analysis with data assimilation, we also examined the clear sky and contextual biases for satellite aerosol products. Research findings from this project are documented through peer-reviewed journal papers and one M.S. thesis (selected publications are attached with this report).

15. SUBJECT TERMS

Aerosol, data assimilation, satellite remote sensing, visibility forecast, electro-optical propagation, MODIS, MISR, CALIPSO, NAAPS, NAVDAS-AOD, clear sky and contextual biases

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FINAL TECHNICAL REPORT

Development of an operational data assimilation package using NAAPS and NAVDAS (Grant Number: N00014-08-1-0264)

Prepared by

Jianglong Zhang
University of North Dakota,
Department of Atmospheric Sciences
Clifford Hall Room 412
4149 University Ave. Stop 9006
Grand Forks, ND 58202-9006
701-777-6342 – voice
701-777-5032 – fax
jzhang@atmos.und.edu

December, 2009

ABSCTRACT

Recently, a new aerosol assimilation model (NAVDAS-AOD) was developed to improve the Navy Aerosol Analysis and Prediction System (NAAPS)'s electro-optical propagation forecast capability. In this project, we developed Quality Control and Quality Assurance strategies for the over-ocean Collection 5 Moderate Resolution Imaging Spectroradiometer (MODIS) aerosol product that will be applied to the operational data assimilation scheme. An observational based Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) climatology was also developed and implemented to NAVDAS-AOD for improving vertical representations of aerosol distributions. We also tested the feasibility of aerosol data fusion with the combined use of the MODIS, MODIS DeepBlue, and the Multiangle Imaging SpectroRadiometer (MISR) aerosol products. Using the NAAPS analysis with data assimilation, we also examined the clear sky and contextual biases for satellite aerosol products. Research findings from this project are documented through peer-reviewed journal papers and one M.S. thesis (selected publications are attached with this report).

LONG-TERM GOALS

One of the strategies to improve the Navy Aerosol Analysis and Prediction System (NAAPS) electro-optical propagation forecast capability is through operational aerosol data assimilation. This process of combining the strength of both near real time aerosol observations and aerosol model predictions has only becomes feasible in the past few years. The assimilation of satellite observations into numerical models is now commonplace. However, only a few attempts have been made to assimilate satellite aerosol products into numerical models. Methods include using an Optimal Interpolation (OI) technique, mainly through retrospective studies or limited regional studies and, most recently, through radiance assimilation. Based on a previous NRL award, a first of its kind aerosol optical depth data assimilation system was developed. Our long term goals are to improve the stability of the system, and to allow for the easy application of data from multiple satellite sensors.

OBJECTIVES

Scientific objectives of this project are tightly aligned with the long-term development of the Navy's atmospheric constituent's data assimilation system – the Navy Variational Analysis Data Assimilation System-Aerosol Optical Depth (NAVDAS AOD). Now that an initial prototype system has been developed, incremental enhancements can be performed. In this one year grant (with one year no-cost extension), we had the following objectives.

1) The original NAVDAS-AOD system was developed with the Moderate Resolution Imaging Spectroradiometer (MODIS) data collection 4 optical depth data. Now obsolete, the system must be adapted and new quality assurance coefficients must be derived for the new MODIS data collection 5.

2) With the new data collection 5 data stream, we wished to perform a multi-year aerosol data assimilation test analysis to gauge model improvement. Included is not only the collection 5 over ocean, but also the NRL provided over land aerosol products generated by Edward Hyer under J. Reid program. Lastly, we wished to test the improvement of satellite data sets of opportunity, such as the Multi-Angle Imaging Spectroradiometer (MISR).

3) Recently we gained access to global space-based lidar data. To aid in the vertical placement problem in aerosol optical depth data assimilation, we wished to develop a 3-D aerosol climatology using multi-year Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) data.

WORK COMPLETED

In summary, we have successfully accomplished the proposed objectives. The algorithm for constructing data-assimilation quality over-water MODIS aerosol product (collection 5) has been developed and transitioned to NRL. The CALIPSO aerosol climatology has been developed and incorporated in the current version of NAVDAS-AOD. The PI also collaborated with Dr. J. Reid from NRL and Dr. Edward Hyer on the over land MODIS aerosol assimilation. Results from Dr.

Hyer showed promising results for the over land assimilations using the quality assured MODIS over land aerosol product.

In addition to the proposed objectives, as part of a future effort on scaling effects, we also began a study in conjunction with NRL Monterey of sample and contextual biases in the over-water MODIS aerosol product, and we published a journal paper on this issue. We also initiated the study of multi-sensor data fusion with the combined use of MODIS, MISR and MODIS DeepBlue aerosol products through aerosol data assimilation. Because quality assurance procedures are still under development, these overland products were taken "as is" with static error fields.

RESULTS

An analysis of clear sky and contextual biases (Zhang and Reid, 2009): Clear sky and other cloud-related contextual biases are critical yet unsolved mysteries for aerosol related climatological studies using satellite observations. For the first time, we simulated contextual biases over ocean using 2-years of Navy Aerosol Analysis and Prediction System (NAAPS) products that include the Moderate Resolution Imaging Spectroradiometer (MODIS) aerosol optical depth (AOD) assimilation. We compared model-derived AOD in regions with and without observations, and found that sampling results in negligible seasonal globally averaged AOD bias (< 5%). Biases are more pronounced in regions with frequent overcast skies and high aerosol loadings, such as Southeast Asia, and mid-latitude South America. This suggests that contextual biases may develop from transport covariance and other observing biases. Lastly, we found that over remote oceans, under cloud decks, a slight increase of aerosol optical depth values could exist, as compared with cloud free regions. However this effect is still small relative to cloud artifacts in the retrieval.

Collection 5 over ocean data quality study (Shi et al., 2009, in preparation): As an update to our previous use of Moderate Resolution Imaging Spectroradiometer (MODIS) over-water aerosol optical depth (τ) Collection 4 data, we examined nine years of Terra and eight years of Aqua data collection 5 data for its potential usage in aerosol data assimilation. Uncertainties in the over-water MODIS τ were studied as functions of observing conditions, such as surface characteristics, aerosol optical properties, and cloud artifacts. Empirical corrections and quality assurance procedures were developed and compared to collection 4 data. After applying quality assurance and empirical correction procedures, the uncertainties in the MODIS Terra and Aqua τ are reduced by 20% and 12%, respectively. Nine years of Terra and eight years of Aqua quality-assured level 3 (daily average) MODIS over-water aerosol products were produced. The newly developed MODIS over-water aerosol products will be used in operational aerosol data assimilation and aerosol climatology studies, and will also be useful to other researchers who are using the MODIS satellite products in their projects.

Multi sensor data fusion: Advanced satellite aerosol optical depth retrievals and datasets now allow the scientific community an unprecedented volume of observations of the global aerosol distribution. Each algorithm has advantages and disadvantages, and no single dataset can boast top performance everywhere over the globe. We developed a multi-sensor aerosol optical depth analysis over Saharan regions by assimilating MODIS operational, MODIS deep blue, and MISR aerosol products into NAAPS via NAVDAS-AOD for June to August, 2005. Our study

suggested that aerosol data assimilation can be a very efficient technique for multi-sensor aerosol data fusion. Our study also suggested that aerosol modeling could in turn greatly benefit from the multi-sensor aerosol observations. A more than 50% increase was found for the correlation between NAAPS and AERONET aerosol optical depth (including both land and ocean) after assimilating data from multi-sensor measurements into NAAPS (Figure 1).

CALIPSO climatology: One of the limitations in the 2-D variational (VAR) analysis of aerosol assimilation is that NAAPS aerosol climatology was used in redistributing the analysis increments from 2-D aerosol optical depth fields to 3-D aerosol mass concentrations. A new CALIPSO climatology is included in the NAVDAS-AOD for a better representation of the aerosol vertical distributions in NAAPS. The CALIPSO climatology is constructed for four seasons, four aerosol types (smoke, dust, sulfate, and sea salt), with spatial and vertical resolution of 5°Lat/Lon, and 250 m-2 km (varying with altitude) respectively. However, insignificant improvements were found in the NAAPS analysis (mostly over small AOD values), and a 3-D var data assimilation package may be necessary for NAAPS to fully benefit from the CALIPSO measurements.

IMPACT/APPLICATIONS

Current Observing System Simulation Experiment (OSSE)'s suggest that the inclusion of over water MODIS AOD data improves the initial root mean square analysis by more than 25-40%. Further, this improvement is shown to hold out through 48 hrs - the longest the OSSE has been performed. Further, the "as is" assimilation of over-land data improves the model in areas of Navy interest, such as Africa and SW Asia. After a proper QC and QA procedure for over-land data is completed (ongoing at NRL Monterey), we expect performance to further increase.

TRANSITIONS

Code for optical depth data assimilation and NAVDAS-AOD has been delivered to NRL Monterey, and is currently transitioned to operation in the Fleet Numerical Meteorological and Oceanographic Center (FNMOC). The algorithm for constructing a data assimilation quality MODIS collection 4 over water product has been delivered as well.
The algorithm for constructing a data assimilation quality MODIS collection 5 over water product has been delivered to NRL Monterey for future implementation to FNMOC.

RELATED PROJECTS

This project is tightly coupled to a number of ONR 322 programs at the Marine Meteorology Division Aerosol and Radiation Section on the further development of the Navy's aerosol forecasting capabilities. This includes an integrated effort with the Earth Sciences Applications project of JS Reid on the development of NAVDAS-AOD, the model integration with the Large Scale Aerosol Modeling Development project of D. L. Westphal, and the ONR Young Investigator Program of Dr. Jianglong Zhang.

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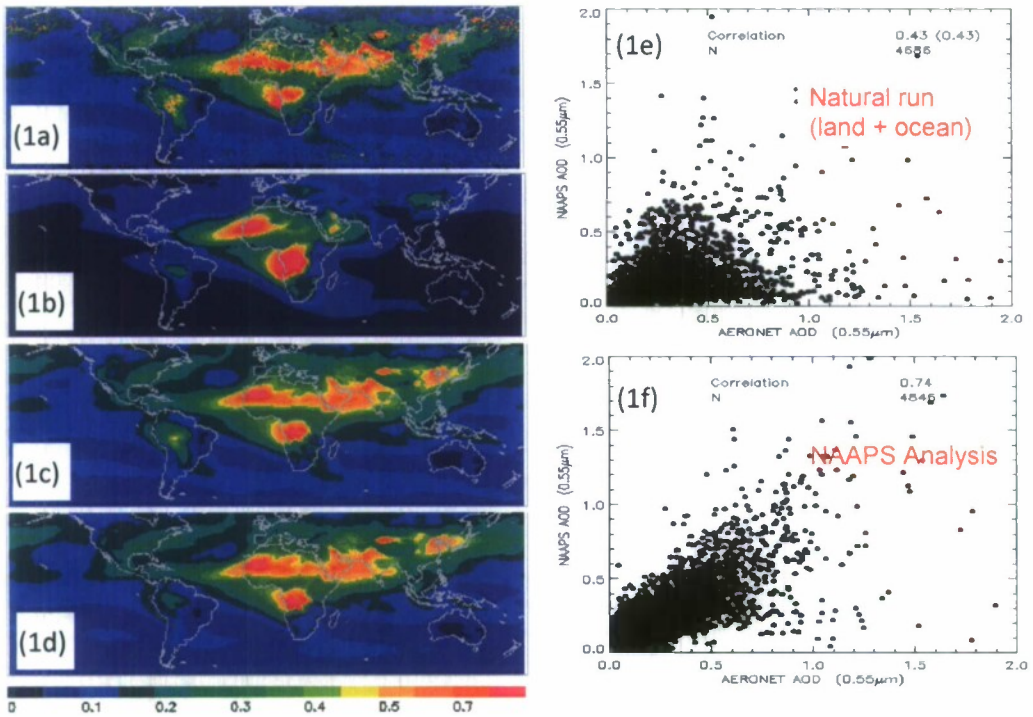

Figure 1a. Three month average of MODIS operational, MODIS DeepBlue and MISR aerosol products for June-August, 2005. 1b) NAAPS AOD forecast for the same study season as Figure 1a. 1c) NAAPS analysis with the inclusion of MODIS operational, MODIS DeepBlue and MISR aerosol products for the same study period as Figure 1a. 1d) Similar to Figure 1c, but for 6 hour forecast. 1e) Inter-comparison of NAAPS and AERONET AOD for NAAPS run without data assimilation for the same study period as Figure 1a. 1f) Similar to Figure 1e but for NAAPS runs with assimilation of the three satellite products as shown in Figure 1c.